Method and device for sensing current

The present invention relates in general to a method and device for sensing current. Particularly, the present invention relates to a method and device for sensing current in a half-bridge driver, for instance in a switching amplifier. More particularly, the present invention relates to a method and device for sensing current in a switched current path, where current is periodically switched between an unknown magnitude during a first part of a period and a predetermined fixed magnitude during a second part of the period.

Fig. 1A illustrates a half bridge driver circuit 1 for generating an AC current in a load L powered from a DC voltage source V_{DC} having a high voltage terminal 2 and a low voltage terminal 3. The half bridge driver circuit 1 comprises a series arrangement of two controllable switches 11 and 12 arranged between said high voltage terminal 2 (V_{HIGH}) and a low voltage terminal 3 (V_{LOW}), wherein the first switch 11 is coupled between the high voltage terminal 2 and a node A, and wherein the second switch 12 is coupled between the low voltage terminal 3 and this node A. The current path between the high voltage terminal 2 and said node A is indicated as first bridge branch 21; the current path between the low voltage terminal 3 and said node A is indicated as second bridge branch 22. Said node A between said switches 11, 12 is coupled to an output terminal 6 via an inductor 4. A capacitor 7 is coupled in parallel to the load L. The switches are usually implemented as MOSFETs, as illustrated.

A switch driver 13 has output terminals 14 and 15, coupled with control terminals of said switches 11, 12, respectively. In a first operative state, which will be referred to as high state, the switch driver 13 is adapted to generate control signals for said switches 11 and 12 such that the first switch 11 is conductive (ON) while the second switch 12 is non-conductive (OFF); in that case, a current I_H will flow through the inductor 4 in a direction from the high voltage terminal 2 to the output terminal 6, causing the voltage level at the output terminal 6 to rise. In a second operative state, which will be referred to as low state, the switch driver 13 is adapted to generate control signals for said switches 11 and 12 such that the first switch 11 is non-conductive (OFF) while the second switch 12 is

conductive (ON); in that case, a current I_L will flow through the inductor 4 in the opposite direction, i.e. in a direction from the output terminal 6 to the low voltage terminal 3, causing the voltage level at the output terminal 6 to drop.

The switch driver 13 has an input terminal 16 receiving timing signals, which control the switch driver 13 to be alternating between its high state and its low state. The resulting currents in the inductor 4 and switches 11, 12 are illustrated in the graph of Fig. 1B.

Fig. 1B is a graph illustrating signal shapes. In the coil 4, a triangular current shape I_4 is generated, having a positive slope during the high state of the switch driver 13, and having a negative slope during the low state of the switch driver 13. The maximal current magnitude is indicated as I_{MAX}, the minimal current magnitude is indicated as I_{MIN}. This current can be considered as a DC current with DC current magnitude I_{DC}, indicated as a dotted line, and positive amplitude I_{MAX}-I_{DC} and negative amplitude I_{MIN}-I_{DC}.

The current I_H through the first switch 11 has the same magnitude as I_4 during the high state of the switch driver 13, but is zero during the low state of the switch driver 13. Similarly, the current I_L through the second switch 12 has the same magnitude as I_4 during the low state of the switch driver 13, but is zero during the high state of the switch driver 13.

Circuits like circuit 1 are used in many types of applications, for instance in drivers for gas discharge lamps, motor drivers, DA power inverters, switching amplifiers, etc. The present invention is not restricted to one of such applications, but can be used in any of those applications, and others not mentioned in the above.

In general, for instance for control purposes, it is desirable to have a measuring signal representing the current I_4 in the inductor 4.

For measuring this current, several possibilities exist, all having drawbacks.

In one possibility, a measuring resistance may be arranged in series with the inductor 4; however, this involves the drawback of increased dissipation. For measuring small current values, this may be found acceptable, but in cases with high currents, e.g. in the order of 50 A, the dissipation in a measuring resistor is unacceptable. Further, using a measuring resistor introduces a problem of galvanic insulation, which is needed to reference the DC level of the measurement signal to the measurement GND level.

In another possibility, a DC current transducer with a Hall-element or the like may be used; however, such devices are not fast enough. In a third possibility, an AC current transducer may be used; however, then no information regarding the DC level of the current is obtained.

In another approach, the coil current is not measured in the common coil branch between node A and output 6, but in each of the switch branches between the high voltage terminal 2 and node A on the one hand and between the low voltage terminal 3 and node A on the other hand. The coil current can be reconstructed from the two measured currents, since the coil current is a summation of the two switch currents, taking the current direction into account.

US-5.815.391 discloses a circuit embodying this approach. This measuring circuit comprises two AC current transformers associated with the respective switch branches. The outputs of the two AC current transformers are added together. Switching circuitry is provided for assuring that, during the period when a switch is non-conductive (off-period), the output signal from the corresponding AC current transformer does not contribute to the overall measuring output signal. This result is achieved by disconnecting the corresponding AC current transformer from a measuring resistor (Fig. 5 of the publication). In another embodiment, two Rogowski flux coils are used, of which the output voltages are integrated and summed. In this embodiment, said result is achieved by making the output of a corresponding integrator equal to zero (Fig. 6 of the publication) during the off-period.

This sensing circuit is only capable of measuring the DC level of the coil current if the integrator is reset at the right moment. Rogowski flux coils are typically bulky, expensive, and have a relatively limited frequency range.

Further, in the embodiment disclosed by the publication, the magnetizing current is driven to zero by a flyback voltage developed over a pair of clamping zener diodes. This will introduce inaccuracies in practical implementations. First, because the inductance of the AC current transformer will resonate with the parasitic capacitance of the secondary winding, so that the magnetizing current will not be driven to zero but will contain a sine-shaped current contribution. Second, the zener diodes will also show a certain leak-current that will introduce non-linearities.

It is a general objective of the present invention to overcome said disadvantages.

Specifically, it is an objective of the present invention to provide a measuring circuit and method capable of providing a measuring signal representing actual value of the coil current, i.e. the AC part as well as the DC part of the coil current.

Further, it is an objective of the present invention to provide a measuring circuit and method capable of accurately sensing current in a switched current path, where current is periodically switched between an unknown magnitude during a first part of a period and a predetermined fixed magnitude during a second part of the period.

According to an important aspect of the present invention, an offset signal is added to the measured current signal, the offset signal being chosen such that, during the off-state of a switch, the corresponding measurement signal is equal to zero. Then, during the on-state of such switch, the same offset is applied, so that the corresponding measurement signal accurately reflects the actual current.

These and other aspects, features and advantages of the present invention will be further explained by the following description of the present invention with reference to the drawings, in which same reference numerals indicate same or similar parts, and in which:

Fig. 1A is a block diagram schematically illustrating a half-bridge driver;

Fig. 1B is a graph schematically illustrating signal shapes at various locations in the half-bridge driver of Fig. 1A;

Fig. 2 is a block diagram schematically illustrating a current sensing circuit according to the present invention.

Fig. 2 is a block diagram schematically illustrating a current sensing circuit 50 comprising a first switch current measuring circuit 100 according to the present invention. The first switch current measuring circuit 100 comprises a current sensing stage 110 and an offset stage 150.

The current sensing stage 110 comprises a current sensor 120, in this embodiment an AC current transformer 120, having a primary winding 121 coupled in series with the first switch 11, and having a secondary winding 122 coupled in parallel to a measuring resistor 123, which has one terminal connected to a reference voltage level, in this case ground. At the opposite terminal of the measuring resistor 123, indicated as point X, a transformer output voltage signal is provided, which will be indicated as intermediate measuring voltage signal V_{HM}, and which has the same shape as the current I_H through the first switch 11 but a DC level V_{DCH} corresponding to the average current magnitude I_{AVH} of

current I_H. Normally, the average current magnitude I_{AVH} of the current I_H through the first switch 11 may be lower or higher than the DC level of the current I_4 in coil 4.

Optionally, the current sensing stage 110 may comprise a buffer circuit 130, as shown.

It is noted that the intermediate measuring signal (V_{HM}) corresponds to an AC part of said current (I_H), although, depending on the embodiment of the current sensor, the intermediate measuring signal (V_{HM}) may comprise a DC part, either caused by said current (I_H) or, as an offset, caused by the sensor itself.

The intermediate measuring voltage signal V_{HM} is coupled to a first input 161 of an adder 160 of the offset stage 150, which comprises an offset generator 170 having an output 172 coupled to a second input 162 of the adder 160. The adder 160 has an output 163 providing a sum signal S1. The offset generator 170 has a timing input 171 for receiving a signal indicating the off state of the first switch 11, i.e. the low state of the switch driver 13. In the embodiment shown, the timing input 171 of the offset generator 170 is coupled to the first output 14 of the switch driver 13. The offset generator 170 further has a feedback input 173 coupled to the output 163 of the adder 160.

The offset generator 170 is designed, during the off state of the first switch 11, to generate at its output 172 an auxiliary signal or offset signal $V_{OFF,H}$ such that the output voltage at the output 163 of the adder 160, indicated at point Z, is equal to zero, corresponding to the fact that during this off state the current I_H trough the first switch 11 is equal to zero.

The offset generator 170 is further designed, during the on state of the first switch 11, to generate at its output 172 the same offset signal $V_{OFF,H}$ as determined during the previous off state period. As a result, the shape of the adder output signal S_1 is an accurate representation of the current I_H in the first switch 11.

In an exemplary embodiment, the offset generator 170 may comprise a control loop for regulating the offset signal $V_{OFF,H}$ during the off state of the first switch 11 in combination with a sample-and-hold circuit for holding the offset signal $V_{OFF,H}$ during the on state of the first switch 11, as will be clear to a person skilled in the art.

Optionally, the offset stage 150 may comprise a buffer circuit 180, as shown.

It is noted that, for some applications, it is sufficient to have a measuring signal accurately reflecting the current in one switch only. Therefore, the switch current measuring circuit 100 is to be considered an embodiment of the present invention.

The current sensing circuit 50 of Fig. 2 is intended to provide a measuring signal accurately reflecting the current in coil 4. Therefore, according to the present invention, the current sensing circuit 50 comprises a second switch current measuring circuit 200 which preferably has an identical design as the first switch current measuring circuit 100. In Fig. 2, components of the second switch current measuring circuit 200 are indicated with the same reference numerals as the corresponding components of the first switch current measuring circuit, increased by 100.

The primary winding 221 of the AC current transformer 220 of the second switch current measuring circuit 200 is coupled in series with the second switch 12, and the timing input 271 of the second offset generator 270 is coupled to the second output 15 of the switch driver 13. The operation of the second switch current measuring circuit 200 is similar as the operation of the first switch current measuring circuit 100, *mutatis mutandis*, so it is not necessary to repeat the explanation of the operation thereof. At its output, the second switch current measuring circuit 200 provides a measuring signal S_2 accurately reflecting the current I_L in the second switch 12.

The current sensing circuit 50 further comprises an adder 300, having inputs 301 and 302 coupled to the outputs of the first and second switch current measuring circuits 100 and 200, respectively, and having an output 303 providing an output signal S3 which is the summation of the measuring signals provided by the first and second switch current measuring circuits 100 and 200; this output signal S3 accurately reflects the current in coil 4.

It should be clear to a person skilled in the art that the present invention is not limited to the exemplary embodiments discussed above, but that several variations and modifications are possible within the protective scope of the invention as defined in the appending claims.

For instance, instead of an implementation on the basis of voltage signals, it is also possible to construct an implementation on the basis of current signals.

Further, the timing signals indicating the ON/OFF state of corresponding switches can be obtained from other sources than the switch driver outputs 14 and 15.

The invention is not restricted to the half-bridge implementation of Fig. 2; the principle underlying the invention is also applicable in the case of a full-bridge implementation.

In the above, the present invention has been explained with reference to an embodiment having two switches connected in series, allowing the current to change direction. However, the invention is not restricted to such implementation; the principle

underlying the invention is also applicable in the case of a buck implementation, wherein one of the switches (for instance: 12) is replaced by a diode, as will be clear to a person skilled in the art.

In the above, the present invention has been explained with reference to a current sensing stage comprising an AC current transformer. Instead, other types of current sensors may be used, for instance magneto-resistive sensors or Hall sensors. Such sensors are capable of measuring DC current, but have a relatively large intrinsic offset; this applies especially to magneto-resistive sensors. Such intrinsic offset can also be corrected by the method proposed by the present invention.

In the above, the present invention has been explained with reference to block diagrams, which illustrate functional blocks of the device according to the present invention. It is to be understood that one or more of these functional blocks may be implemented in hardware, where the function of such functional block is performed by individual hardware components, but it is also possible that one or more of these functional blocks are implemented in software, so that the function of such functional block is performed by one or more program lines of a computer program or a programmable device such as a microprocessor, microcontroller, etc.

Specifically, at point X, the signal can be made digital by an AD converter, and all further processing can be done in software.